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AlGaN/GaN HEMT high-power and low-noise performance at $f \geq 20$ GHz

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Abstract

In this paper, we report on the power and noise performance of AlGaN/GaN HEMTs in the K (18 – 27 GHz) band. At 20 GHz, a record CW output power of 2 W with an associated gain of 8 dB and PAE of 33 % has been achieved on a 8-finger 0.2 μm x 500 μm device. Minimum noise figure of 1.4 dB has been achieved on a 0.15 μm x 200 μm device at 26 GHz. The data demonstrate the viability of AlGaN/GaN HEMTs for high-frequency power and LNA applications.

I. Introduction

The high breakdown fields, high electron saturation velocity, and high electron densities in AlGaN/GaN HEMT structures have led to microwave power performance significantly exceeding the performance of state-of-the-art GaAs and InP-based devices [1-3]. Demonstrated low minimum noise figures make AlGaN/GaN HEMTs very attractive for use in robust low-noise amplifiers (LNAs). Low-noise, high breakdown GaN HEMTs [4] in amplifier front-ends eliminate the need for diode limiters as protection against RF overstress. This can reduce the overall LNA noise figure by 1dB. While the performance of GaN HEMTs in the L-Ku bands has been thoroughly investigated in recent years, very few reports are available on the operation of these devices at frequencies above 18 GHz [2,5]. These frequencies are important for satellite communication and high-performance radar applications. In this paper, we report on the power and noise performance of AlGaN/GaN HEMTs in the K (18 – 27 GHz) band.

II. Device Fabrication

The AlGaN/GaN structures were grown by metalorganic chemical vapor deposition (MOCVD) on top of semi-insulating 4H-SiC substrates and showed an average sheet resistance in the range of 350-450 Ω/sq. The device mesa etch was performed using Cl_2/BCl_3 ICP etching technique. Ti/Al/Ni/Au ohmic contacts with an

average contact resistance of 0.6-0.8 Ω mm were formed by alloying at 880 °C in a nitrogen atmosphere. Electron beam lithography was utilized to fabricate 0.12-0.2 μm Pt/Au T-gates in a 2 μm source-drain region. The source to gate distance was 0.8 μm. The devices were passivated with PECVD SiN and two levels of interconnect metal including airbridges were used for external connections. The AlGaN/GaN HEMTs had a peak transconductance of ~ 300 mS/mm and a maximum drain current density in excess of 1 A/mm (measured at $V_G = +1V$). The typical on-state breakdown voltage was 35-40 V. A negative output conductance was observed under high bias conditions for large gate periphery devices due to self-heating effects. Small-signal RF measurements yielded a unity gain cut-off frequency (f_t) of 34 GHz for HEMTs with 0.2 μm gates, 44 GHz for 0.15 μm devices, and 50 GHz for 0.12 μm HEMTs. The maximum frequency of oscillations (f_{max}) was around 77 GHz for 0.15 and 0.2 μm-gate devices and 103 GHz for 0.12 μm HEMTs.

III. Microwave Power Performance

Continuous wave power measurements at 20 GHz were performed on 8-finger devices with the total gate periphery of 500 μm and the gate pitch of 40 μm using a Q-band Focus load-pull system. The results of the on-wafer load-pull measurements are shown in Fig. 1.

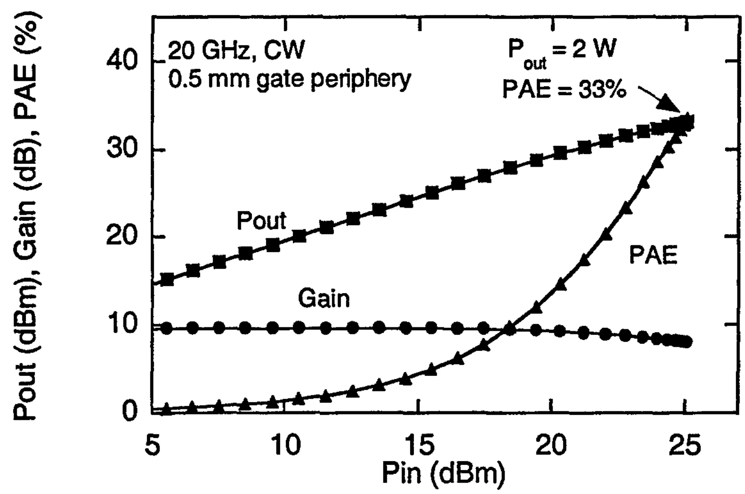

Figure 1. Power performance of a 500 μm AlGaN/GaN HEMT showing a total CW output power of 2 W at 20 GHz. The device was biased at $V_{DS} = 25$ V and $I_{DS} = 250$ mA.

When biased and tuned for the maximum output power, the device under investigation showed the total output power of 2 W with an associated power added efficiency (PAE) of 33 % and gain of 8 dB. To the best of our knowledge, this is the highest total output power reported for AlGaN/GaN transistors at 20 GHz. Note, that the device was not driven far into gain compression in this case and the measured maximum output power was limited by the available input drive power.

IV. Microwave Noise Performance

High frequency noise performance of the devices was measured using an ATN noise parameter test set. Noise figure measurements have been performed from 2 to 26 GHz. A plot of the noise characteristics as a function of frequency for a 0.12 μm gate device (wafer A) and a 0.15 μm device (wafer B) with the total gate peripheries of 200 μm is shown in Figure 2. The minimum noise figure of 1.4 dB was achieved for the AlGaN/GaN HEMTs at 26 GHz. This is comparable to the NF_{min} of 1.4-1.6 dB typically demonstrated by GaAs HEMTs at this frequency.

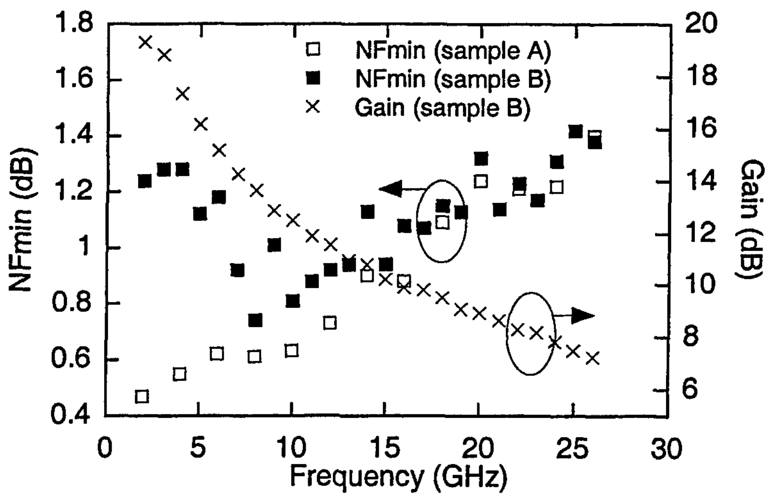

Figure 2. Minimum noise figure versus frequency for a 0.12 μm AlGaN/GaN HEMT (wafer A, open squares) and a 0.15 μm gate device (wafer B, dark squares) with the gate peripheries of 200 μm. The associated gain is shown for a 0.15 μm HEMT (crosses). The devices were biased at $V_{DS} = 15$ V and $I_{DS} = 12$ mA.

An unusual behavior of F_{min} is observed for wafer B below 10 GHz where the device noise increases with decreasing frequency. Similar $1/f$ dependence of NF_{min}

below ~ 8 GHZ is often observed in InP/InAlAs/InGaAs HEMTs [6]. In InP-based devices, the upturn in the minimum noise figure at high drain-source biases is typically attributed to the increase in the gate current dominated by impact ionization process in the InGaAs channel [6,7].

However, for a typical wide-band gap AlGaN/GaN HEMT one would not expect significant impact ionization to occur at moderate V_{DS} voltages. This is exemplified in our results from wafer A's devices which do not exhibit $1/f$ dependence of NF_{min} (Fig.2) or impact ionization gate current (Fig.3(a)). On the other hand, devices from wafer B do exhibit the bell-shaped feature in I_G-V_G plots (Fig.3(b)), which is the signature of impact ionization generated gate current [8].

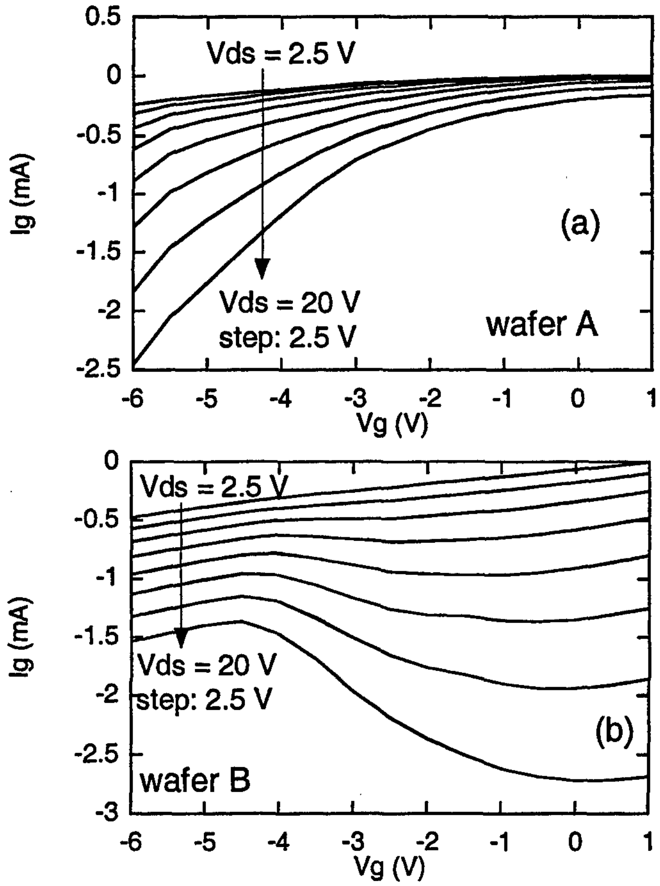

Figure 3. Gate current I_G versus gate-source voltage V_G for (a) a 0.12 μm x 200 μm AlGaN/GaN HEMT on wafer A, and (b) a 0.15 um x 200 um device on wafer B for different drain-source voltages.

The impact ionization gate current for the devices on wafer B correlates to significant increase in the low-frequency noise. Figure 4 shows that the magnitude of $1/f$ dependent NF_{min} increases almost proportionally with impact ionization generated gate current. On the other hand, devices on wafer A do not show any evidence of the impact ionization and, as a result, the low-frequency noise is significantly smaller in this case. More studies are currently under way to determine the reasons for such a significant difference in the device behavior between different AlGaN/GaN wafers.

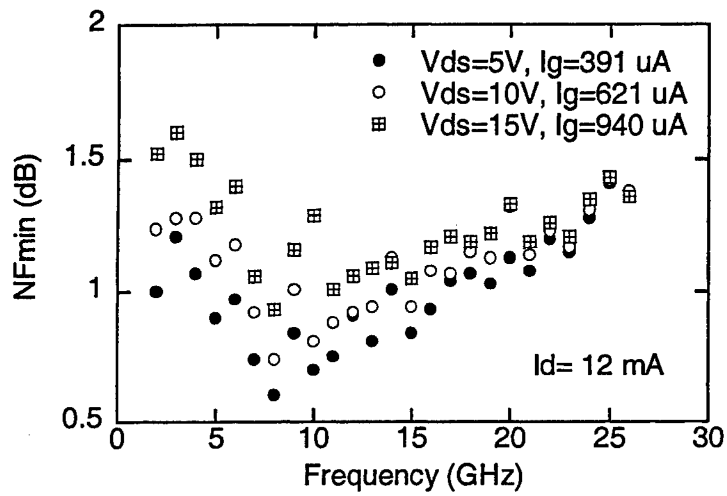

Figure 4. Minimum noise figure versus frequency for a 0.15 µm x 200 µm AlGaN/GaN HEMT (wafer B) at different values of V_{DS}: 5 V (dark circles), 10 V (open circles) and 15 V (squares with crosses). The drain current was kept constant at 12 mA.

V. Summary

In summary, we demonstrated an excellent power and microwave performance of AlGaN/GaN HEMTs at $f \geq 20$ GHz. The maximum total CW output of 2 W with an associated power added efficiency of 33 % and gain of 8 dB was measured on a 8-finger 500 µm device. Minimum noise figure of 1.4 dB has been achieved on a 0.15 µm x 200 µm device at 26 GHz. The presented data demonstrate the viability of AlGaN/GaN HEMTs for high-frequency power and LNA applications.

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